Structural Properties of Hybrid Star with CFL locking in Quark Phase

Suman Thakur* and Shashi K. Dhiman†
Department of Physics, Himachal Pradesh University Shimla-171005, INDIA

Introduction

Compact stars are some of the densest manifestations of massive objects in the universe. They are ideal astrophysical laboratories for testing theories of dense matter physics and provide connections among nuclear physics, particle physics, and astrophysics. Compact stars may exhibit conditions and phenomena not observed elsewhere, such as hyperon-dominated matter, deconfined quark matter, superconductivity with critical temperatures near 10^{10} kelvin, opaqueness to neutrinos, and magnetic fields in excess of 10^{18} Gauss. The appearance of quark matter or hadron-quark mixed phase in the massive neutron stars is a hot topic in the study of compact objects. A family of compact stars consisting completely of the deconfined mixture of u, d, s quarks has been called Quark stars [1]. The compact stars with a quark matter core, either as a hadron-quark mixed phase or as a pure quark phase, are called hybrid stars (HyS) [3]. The main objective of present work is to investigate the Equations of State and Mass - Radius relationship of Hybrid Matter Star. Here the Hadron phase id described within the framework of FTRMF model [2] and Quark phase is described within the framework of Quark Quasiparticle (QQPM) model.

Theoretical Framework

We construct the mixed phase of EOS made up of the hadron matter and quark matter by employing the Glendenning construction [3] for hybrid compact star. The equilibrium chemical potential of the mixed phase corresponding to the intersection of the two surfaces representing hadron and quark phase can be calculated from the Gibbs condition for mechanical and chemical equilibrium at zero temperature which reads as,

$$P_{HP}(\mu_e, \mu_n) = P_{QP}(\mu_e, \mu_n) = P_{MP}, \quad (1)$$

In the mixed phase the local charge neutrality condition is replaced by the global charge neutrality which mean that both hadron and quark matter are allowed to be charged separately. The condition of the global charge neutrality can be expressed as;

$$\chi\rho_c^{QP} + (1-\chi)\rho_c^{HP} = 0, \quad (2)$$

where, χ the volume fraction occupied by quark matter in the mixed phase in terms of charge density ρ_c. The value of the χ increases from zero in the pure hadron phase to $\chi = 1$ in the pure quark phase. The energy density $\mathcal{E}_{MP}$ and the baryon density ρ_{MP} of the mixed phase can be calculated as

$$\mathcal{E}_{MP} = \chi\mathcal{E}_{QP} + (1-\chi)\mathcal{E}_{HP} \quad (3)$$

$$\rho_{MP} = \chi\rho_{QP} + (1-\chi)\rho_{HP} \quad (4)$$

1. Results and Discussions

In our calculations, the BSR12 parameter set [2] is used in the framework of extended FTRMF to describe hadrnonic matter. We choose the strange quark mass m_s = 150 MeV, the bag constant $B^{1/4}$ = 170 MeV, to study the interaction of quarks, the CFL energy gap Δ changes from 50 to 70 MeV. Figure(1)presents the EOS of hybrid stars with the CFL quark matter cores. From Figure(1), we find that with increase in the CFL gap parameter from 50 MeV to 90MeV,

*Electronic address: `sumanthakur88@gmail.com`
†Electronic address: `shashi.dhiman@gmail.com`

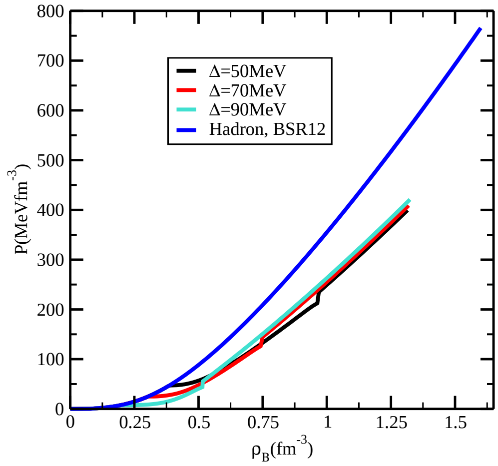

FIG. 1: The complete EOS of hybrid star which include hadronic, mixed, and quark phase in the form of pressure versus energy density. The EOS have been calculated with FTRMF+QQPM models be employing chemical potential dependent effective Bag Function(B^*)

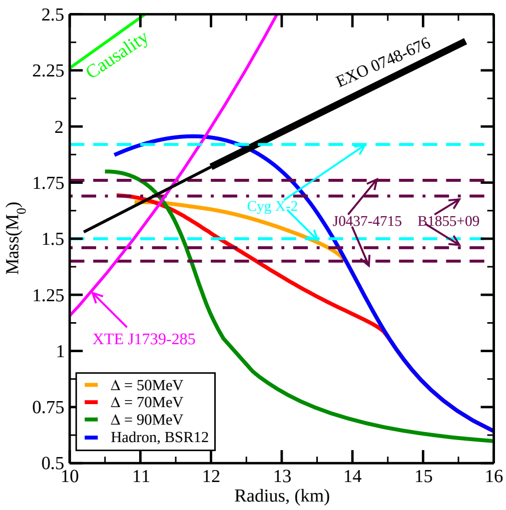

FIG. 2: The Mass-Radius relationship for hybrid star compared with pure Hadron Matter star with bag constant $B_0^{1/4}$ = 170MeV for BSR12 parametrisation at different CFL pairing gaps.

the length of mixed phase region decreases. Simultaneously, there is early appearance of mixed region with larger value of CFL gap parameter Δ

With the hybrid star EOS shown in Figure(1), the corresponding mass - radius relations of the hybrid stars is obtained by solving the Tolman - Oppenheimer - Volkoff (TOV) equations. Figure(2)demonstrates the mass - radius relations with the change of the CFL energy gap, Δ = 50 - 90 MeV. It also shows an interesting phenomenon. When the CFL energy gap increases from 50 to 90 MeV, the maximum mass of hybrid star increases from 1.66$M_\odot$ to approximately 1.80$M_\odot$ ($M_\odot$ is the solar mass), the corresponding radius is from 11.03km to 11.75km. The region excluded by causality (green solid line) and rotation constraints of neutron star XTE J1739-285 (magenta solid line) are given. The compact stars mass limits for J0437-4715, Cyg X-2 and B18509 are plotted for compari- son.The limits on compact star mass and radius from Ozels analysis of EXO 0748-676 [31] with 1σ (dark solid black line) and 2σ (extended black line) error bars are shown.

TABLE I: For Hybrid Matter Star, the variation in gravitational maximum mass in unit of solar $M_\odot$, gravitational radius R in km and $R_{1.4}$ in km of quark stars with parameter BSR12 for Hadron Phase..

Δ(MeV)	$M_{max}(M_\odot)$	$R(km)$	$R_{1.4}$(km)
50	1.66	11.03	13.90
70	1.69	10.68	12.64
90	1.80	10.50	11.36
Hadron	1.96	11.75	13.91

References

[1] X.Y. Lai, R.X. Xu, Astropart. Phys. 31, 128 (2009) .

[2] Shashi K Dhiman, Raj Kumar, and B.K.Agrawal, Phys Rev. C 76, 045801 (2007).

[3] N. K. Glendenning, Compact Stars: Nuclear Physics, Particle Physics, and General Relativity (Springer-Verlag, New York, 2000).